Magnetic Polarization of Au Layers in M/Au Metallic Multilayers (M=Fe, Co, Ni) Investigated by Mossbauer Probe Atoms (SOLID STATE CHEMISTRY-Artificial Lattice Allolys)

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Nobuyoshi Hosoito, Takeshi Emoto, Sunao Hamada and Teruya Shinjo

Magnetic polarization of nonmagnetic Au layers in ferromagnetic/ nonmagnetic metallic multilayers was probed by ^{119}Sn and ^{57}Fe Mössbauer spectroscopy. The Mössbauer probe atoms located in the Au layer with various depths from the interface show depth-dependent large hyperfine field, indicating magnetic polarization in the Au layer. The depth profiles of the magnetic polarization are discussed in Fe/ Au, Co/ Au and Ni/ Au systems.

Keywords: Magnetic polarization/ Metallic multilayer/ Mössbauer spectroscopy

Recently much attention has been paid to the properties of multilayers consisting of alternating magnetic and nonmagnetic materials. Parkin et al.[1] reported long-period oscillations in the exchange coupling of two ferromagnetic layers separated by a nonmagnetic spacer layer as a function of the thickness of the nonmagnetic layer. Oscillatory coupling as a function of spacer layer thickness was found in Fe/Cr, Co/Cr, Co/Ru, Co/Cu, Fe/Cu and numerous other systems.[2-5] To understand the origin of the indirect exchange coupling through the nonmagnetic layer, it is important to investigate the magnetic properties of nonmagnetic spacer layers in the multilayers. Furthermore we stress that investigation of the magnetic properties of the nonmagnetic layers contacting with the ferromagnetic layers is of great importance irrespective of the oscillatory behavior, because the contact of the ferromagnetic layer to the nonmagnetic layer should change the electronic state of the nonmagnetic layer.

In this report, we will present the results of Mössbauer measurements on M/Au (M=Fe, Co and Ni) multilayers with ^{119}Sn and ^{57}Fe probes in the Au layers. The multilayers were prepared by alternate vacuum evaporation under ultra-high vacuum. The Mössbauer probe atoms, ^{119}Sn or ^{57}Fe, are inserted into the Au layer with changing their depth from the M/Au interface. The thicknesses of probe layers are 1.5 Å for Sn and 1 Å for Fe, which correspond to half a monolayer.

SOLID STATE CHEMISTRY —Artificial Lattice Alloys—

Scope of research

By using vacuum deposition method, artificial multilayers have been prepared by combining various metallic elements. The recent major subject is an interplay of magnetism and electric transport phenomena such as the giant magnetoresistance effect. Fundamental magnetic properties of metallic multilayers have been studied by various techniques including Mössbauer spectroscopy using Fe-57, Sn-119, Eu-151 and Au-197 as microprobes, and neutron diffraction. Preparation of microstructured films is attempted and novel magnetic and transport properties are investigated.

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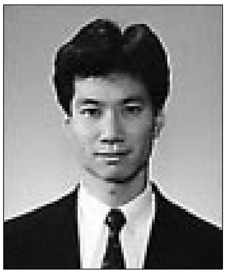

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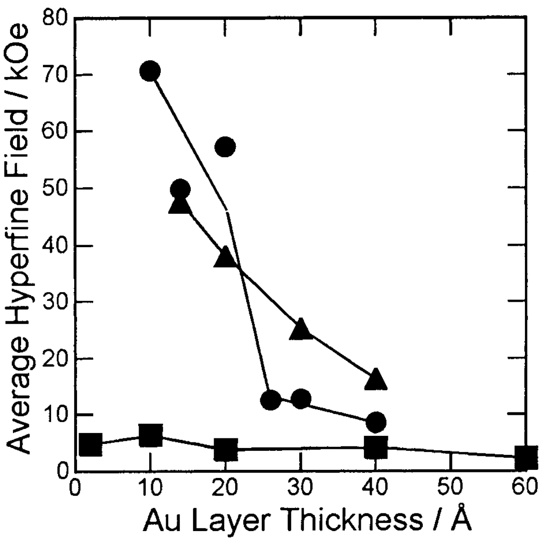

Figure 1. Au layer thickness dependence of Sn average hyperfine field in Fe/Au (triangle), Co/Au (circle) and Ni/Au (square) multilayers. The Sn probes are inserted in the center of the Au layer.

Transmission Mössbauer spectra were measured with a conventional Mössbauer spectrometer with a velocity transducer, a multichannel analyzer and a proportional counter. Measuring temperature is varied between 4.2 K and room temperature. In this report, we will discuss the results at room temperature

Due to the depth-selective insertion of the Mössbauer probes, the Mössbauer spectra offer us very local information about the electronic state of the Au layer. However the Sn and Fe probes indicate somewhat different information on the magnetic polarization of the Au layer because the Sn atoms have no magnetic moment and the Fe atoms have magnetic moment. The Sn nuclei directly sense the magnetic polarization of the Au layer as a hyperfine field. On the other hand in the case of Fe probes, the magnetic polarization acts as an effective field on the Fe magnetic moments to slow down their thermal fluctuation rate. As a result, the Fe nuclei feel a hyperfine field if the magnetic polarization is strong enough. Therefore in both cases, the hyperfine field is thought to be a measure of the strength of the magnetic polarization in the Au layer though the detailed mechanism is different in both cases.

Among the comprehensive studies, a typical result for Sn obtained at room temperature is shown in Fig.1. A series of samples with the structures of …/M(20 Å)/ Au(*X*/2 Å)/ Sn(1.5 Å)/ Au(*X*/2 Å)/M(20 Å)/…, where M=Fe, Co and Ni, is prepared with varying the Au layer thickness *X*. The average hyperfine field at the central point of the Au layer (depth=*X*/2) is obtained from the fitting of the Sn Mössbauer spectrum. In the case of M=Fe (triangle in Fig.1), the average hyperfine field smoothly decreases with increase the depth of the Sn probe *X*/2. In contrast, the average hyperfine field for M=Co (circle) changes suddenly at around *X*/2=10. The average hyperfine field with $X/2 \leq 10$ is very large, but the average hyperfine field with $X/2 > 10$ becomes small. In the case of M=Ni (square), the average hyperfine field is about 5 kOe. This value is, of course, very small. However, it is quite sure

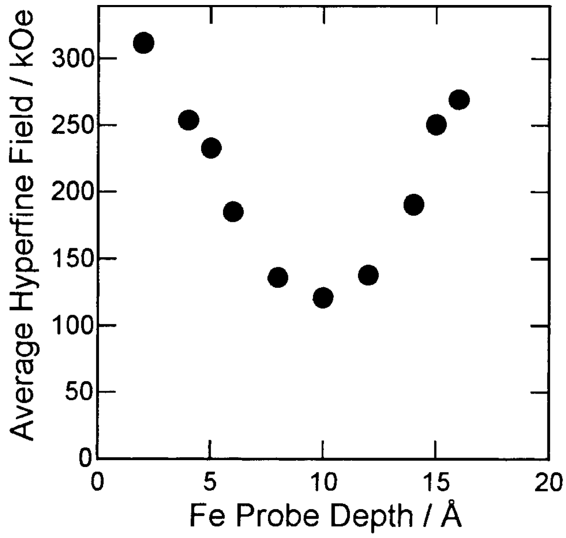

Figure 2. Fe probe depth dependence of average hyperfine field in the Co/Au multilayer.

that the Sn probe atoms feel non-zero hyperfine field if we compare the peak widths of the Mössbauer spectra for the Ni/Au(Sn) multilayers with an Au(Sn) reference film. At present stage, these features including the temperature dependence cannot be explained with any simple model. Band calculations with a realistic approximation are desired.

Figure 2 shows an example using Fe probes. The sample structure is …/Co(20 Å)/ Au(20-*t* Å)/ Fe(1 Å)/ Au(*t* Å)/Co(20 Å)/… i.e. the Fe probe atoms are inserted into various depth *t* from the Co-Au interface of the Co(20 Å)/ Au(20Å) multilayer. The obtained average hyperfine field at room temperature is plotted against the Fe probe depth *t*. The result shown in Fig.2 is qualitatively consistent with that obtained with the Sn probes. The advantage in using Fe as a probe is higher resolution in the Mössbauer peak width than that of the Sn probe case. Indeed, layer-by-layer resolution is obtained in the profiles of the Mösbauer spectra.[6] The average hyperfine filed is indirectly related to the magnetic polarization through a thermal fluctuation phenomenon of the Fe magnetic moment. To obtain a quantitative estimation of the magnetic polarization of the Au layer from the obtained average hyperfine field, Mössbauer measurements in the applied filed are necessary and are under way.

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